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MEASURES OF EFFECTIVENESS IN LOGISTICS

David A. Schrady

May 1989

Prepared for:
Naval Postgraduate School
Monterey, CA 93943

NAVAL POSTGRADUATE SCHOOL,
MONTEREY, CALIFORNIA

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This report was prepared in conjunction with research conducted for the Navy Logistics Research and Development Program and funded by the Naval Postgraduate School.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
NPS55-89-07

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Naval Postgraduate School

6b. OFFICE SYMBOL *(If applicable)*
55

7a. NAME OF MONITORING ORGANIZATION
Navy Logistics Research and Development Program

6c. ADDRESS *(City, State, and ZIP Code)*
Monterey, CA 93943-5000

7b. ADDRESS *(City, State, and ZIP Code)*
Code 5505R, Naval Supply Systems Command
Washington, DC 22202

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
Naval Postgraduate School

8b. OFFICE SYMBOL *(If applicable)*
55So

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
O&MN - Direct Funding

8c. ADDRESS *(City, State, and ZIP Code)*
Monterey, CA 93943-5000

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
Measures of Effectiveness in Logistics

12. PERSONAL AUTHOR(S)
David A. Schrady

13a. TYPE OF REPORT
Technical

13b. TIME COVERED
FROM ________ TO ________

14. DATE OF REPORT *(Year, Month, Day)*
1989, May 15

15. PAGE COUNT

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Logistics, Measures of Effectiveness, Operational Logistics

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This report examines measures of effectivness in naval logistics. Logistics is a warfare support function and it is most desirable to be able to relate resources committed for logistics capabilities to warfare outcomes. In general this cannot be done. Examples of the sorts of measures of effectiveness used in acquisition logistics and in in-service support are given. Battle group logistics, a part of operational logistics, is examined not so much from the viewpoint of measures of effectiveness as from the viewpoint of tactically meaningful measures of logistics resources. Keywords: Sustainability, planning models, replenishment time, time off station, minimum levels. (KR) ←

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
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22b. TELEPHONE *(Include Area Code)*
(408) 646-2801

22c. OFFICE SYMBOL
55So

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

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MEASURES OF EFFECTIVENESS IN LOGISTICS

A. INTRODUCTION

A measure of effectiveness (MOE) is an objective, quantitative expression of performance appropriate to the context in which it is being used. Generally a MOE is an expression that relates resources input to obtain a given measure of output. Return on investment or miles per gallon are possible MOEs for the performance of a firm or automobile respectively. MOEs can also relate solely to output measures; tons of shipping which arrives safely at its destination, for instance.

To be legitimate, the MOE must have real scales on which to measure inputs and outputs. For the firm both investment and return are naturally measured in dollars and return on investment is simply their ratio. For the automobile both miles and gallons can be objectively measured, though on different scales. The challenge in most situations is the measurement of the input, output or both. Cost effectiveness or "bang per buck" is an attractive and frequently used MOE. However while cost is usually measured in dollars, effectiveness is more difficult to characterize and measure. Return on investment may be useful to describe how the assets of a charitable foundation are managed, but this MOE is not useful to characterize the operations or programs of the foundation; programs may include the support of young artists or the purchase of land for preserving open space for example. One can measure the resources consumed but how should the outputs (activities supported) be characterized? The defense of the country can be characterized in terms of inputs (costs), but how should the output be measured?

Defense is purposeful but not inherently economic in nature. Still in peacetime, which thankfully is most of the time, economics dominate all decisions in defense. This is a fact of life as all resources (dollars, manpower, other) are finite and therefore must be explicitly allocated. Nonetheless the quest for reasonable output measures and therefore MOEs is an important on-going problem.

Notice also that MOEs in the affairs of man and society tend to be relative rather than absolute. There is no best return on investment (unless on wants to think that an infinite rate is best) and companies may be judged against the norms for their industry. The classical question in defense is "how much defense is enough?" The answer is relative rather than absolute. It is also a question which is political rather than analytical in nature; analysis helps but fundamentally cannot provide the answer.

While such global questions as how much defense is enough are unanswerable, MOEs are useful in more limited decisions such as the choice between alternative capital investment projects or weapon systems or how a given process should be controlled (physical distribution for example). The above introduces a few of the primary issues associated with MOEs in general. Interest here is limited to MOEs for logistics, specifically naval logistics and, even more narrowly, combat logistics (to be defined subsequently).

B. LOGISTICS

"Logistic" is from the Greek logistikos meaning skilled in calculation. Further Webster's defines logistics as the branch of military science having to do with moving, supplying, and quartering troops. These definitions imply that logistics involves the care and feeding of combat forces and is supported by significant amounts of calculation; calculation of requirements whether they be transport, bullets or beans.

Before focusing on military logistics it is useful to note some of the characteristics of material logistics systems in the private sector. One textbook on the subject, Ref(1), defines business logistics as physical distribution, materials management, and logistics engineering with the foregoing involving the activities of transport, storage, packaging, materials handling, order processing, forecasting, production planning, purchasing, inventory control, and site location. Within a given firm the logistics system is designed to accommodate the steady-state, current situation. One hopes always for greater volumes or new markets but the business logistics system is largely sized to current operations. Blood banks are about the only case where the system is structured to accommodate operations levels above the steady-state level; e.g., disasters. Another characteristic of business logistics systems is that requirements are predictable and the locations at which the requirements are generated, both within and outside the firm, are known. In commercial firms such as Safeway, Texaco, Federal Express, or Sears an approach to logistics management is to set product availability or service levels and then minimize the cost of the logistics system which provides these performance levels. This approach avoids the need to estimate stockout costs or failure to meet due dates. An option in business logistics systems is to contract for parts of the system. Britain's largest department store chain, Marks & Spencer, contracts for its entire physical distribution system.

Military logistics systems differ in important ways. For the military, peacetime is the steady-state and while economics would dictate the minimum cost system which adequately supports peacetime requirements, the military logistics system must be sized for the contingency of war. In practice military logistics systems are sized somewhere between peacetime and wartime requirements from peacetime cost considerations. Another difference between logistics in the private sector and in the military is that, largely, the private sector knows what and where its requirements arise. For the military some requirements are predictable but others are less so: e.g., logistics to support recent naval operations in the Persian Gulf or the British experience in the Falklands war. One could set performance levels if requirements could be well stated. However wartime requirements are scenario dependent and too costly to provide for in peacetime. A quote from a recent Navy logistics workshop, Ref(2), pertains:

> Don't get bogged down by the fact that the logistics system today is a pipeline without water; in peacetime we can never keep the pipeline full - Congress will not allow us to do so. Let's design a good pipeline and see that it will support future needs.

As to contracting for its logistics system components, the military does so to the extent feasible, but one cannot contemplate Federal Express delivering ordnance to a carrier battle force in the North Norwegian Sea in wartime.

C. NAVAL LOGISTICS

OPNAVINST 4000.85, Ref(3), defines naval logistics as consisting of three parts: 1) acquisition logistics, 2) in-service support, and 3) operational logistics. Acquisition logistics involves support systems (ILS and operational support systems), commodities, facilities, and ordnance. In-service support includes the Navy Supply System, maintenance, and bases and base operating support. Operational logistics includes CONUS ports, strategic lift, in-theater support services, shuttle lift, battle force/unit logistics, and operational logistics planning.

A subset of operational logistics is defined here as combat logistics. By combat logistics is meant just fuel and ordnance stocks within a battle group, battle force, or fleet in conflict. In terms of the OPNAV instruction, one might argue that business logistics usually include only acquisition logistics and in-service support and that there is no analogy of operational logistics in the private sector.

The purpose of the naval logistics system is to support the Maritime Strategy which calls for forward deployment of the fleet in peacetime and fighting forward in wartime. It is obvious that significant logistics are required if the fleet is to go forward, remain there, and fight there if necessary. Beyond this, the relationship between logistics and warfighting outcomes is not obvious.

The problem is one of MOEs that relate logistics to warfighting. In this regard logistics is not so different from other non-kill aspects of modern warfare like electronic warfare, command and control, intelligence, or even research and development. All warfare support areas have the problem of being able to relate directly and convincingly their contributions to warfare outcomes. In logistics a few situations in which adequate MOEs might make a difference are as follows:

- The decision between buying a combat logistics force (CLF) station ship or buying another combatant ship;
- The decision between buying advanced base functional components (ABFCs) or buying a new weapon, platform or even manpower;
- The decision between buying stocks of ordnance or funding increased flying hours and steaming days; and
- The decision to build the AOE-6 class CLF ship with less capability than the AOE-1 class CLF ship.

No criticism of past decisions is implied or intended. What is being asserted is that there is a need for MOEs for logistics that relate inputs for logistic capabilities to outputs which are warfighting capabilities.

D. LOGISTICS MOES

In this section some measures of effectiveness used in in-service support logistics and logistics planning models are discussed. The common theme of these measures is that while they are in use currently, they generally relate dollars spent on logistics resources to logistics output measures rather than to warfighting outcomes. This is easy to note and criticize, but alternatives are not offered at this time either.

1. MEASURES OF EFFECTIVENESS FOR IN-SERVICE SUPPORT

Three processes which are a part of in-service support are provisioning, inventory control, and allowance list construction.

a. PROVISIONING

The Naval Supply System has a new provisioning model currently being programmed at the Fleet Material Support Office as FD-PD 96, Refs(4,5,6). Provisioning is the acquisition of an initial stock of spare parts for a new equipment or system to satisfy demands from the date of initial operational capability until the Supply System takes over replenishment responsibility (typically 2-2.5 years).

Provisioning models attempt to allocate optimally a given provisioning budget, where "allocate optimally" means deciding the range and depth of spares to purchase so as to provide the best performance during the provisioning period with respect to the chosen measure of effectiveness. Possible measures of effectiveness include 1) units short, 2) requisitions short, 3) time-weighted units or requisitions short, 4) essentiality-weighted units or requisitions short, 5) mean supply response time, or 6) system availability. Of these measures, system availability is the most attractive; it is the bottom line for the operators of the system. The least attractive is units short which is equivalent to saying "parts is parts" ala the fried chicken fast food commercial on TV; the length of time for which the spare part is out of stock is of no consequence either.

System or operational availability is defined as A_O:

$$A_O = MTBF/(MTBF + MTTR + MSRT)$$

where

MTBF = mean time between failures
MTTR = mean time to repair
MSRT = mean supply response time.

As attractive as A_O is conceptually, computing it for a real system requires making an unsatisfactory number of simplifying assumptions. At this point however note that A_O depends in part on mean supply response time. MSRT is in turn equivalent to (a linear function of) time-weighted units short. Thus the measure of effectiveness in the new Naval Supply System wholesale provisioning model is the minimization of MSRT subject to the provisioning budget. The budget - budgets really, one for consumable items and one for reparable items - is determined from a separate model specified in DODINST 4140.42, Ref(7).

b. INVENTORY CONTROL

Mathematical inventory control theory dates from 1915 when F.W. Harris developed the "economic order quantity" formula. In his formulation Harris postulated that the relevent costs were those of ordering and holding stock and the stockout cost incurred when there were shortages. The economic order quantity is then derived as the order quantity which minimizes the sum of ordering, holding, and shortage costs. There are numerous problems with this, even today, popular formulation. Navy accounting systems are not structured to produce estimates of any of these costs. Further, implicit in the formulation is the assumption that you can afford to buy an economic order quantity. In the Navy monies for replenishment stock are appropriated by material cognizance class, are always limited, and items within the class essentially compete with one another for a share of the available dollars. Thus while the economic order quantity is a single item, unconstrained optimization formulation, the real Navy situation requires a multi-item constrained optimization.

When inventory control decision rules were computerized in the Navy in the early 1960s, the economic order quantity formulation was employed with the shortage cost being imputed from the procurement budget. This approach necessarily applies the same shortage cost (Lagrange multiplier really) to all items - "parts is parts" again. The shortcomings of this approach were appreciated and in the early 1970s the nominal measure of effectiveness changed from the minimization of variable costs to the minimization of mean supply response time subject to the procurement budget constraint.

c. ALLOWANCE LISTS

While Navy provisioning and inventory models employ a minimization of mean supply response time subject to the budget constraint formulation, allowance lists construction employs no optimization model at all. Allowance lists are compiled from the Fleet Logistics Support Improvement Program procedure which, on an item by item basis, determines if the item (spare part) will be on the list from either demand-frequency or insurance criteria. If an item qualifies as demand-based, its depth is set so as to provide a given level of protection against stockout for the relevent period of time. The protection level is 90% and the time period is 90 days. Insurance items are items which fail to qualify as demand-based, are thought to be critical nonetheless, and are carried in minimum depth.

d. SUMMARY

The in-service support measures of effectiveness for provisioning, inventory control, and allowance lists are related to service levels; minimize mean supply response time or minimize the probability of stockout. These are reasonable measures but they relate supply operations to supply measures (or logistics measures). They do not relate supply operations to warfighting outcomes. One can broadly sketch the chain of events from the successful operation of the radar, fire control computer, launcher, and missile of a surface conbatant that allowed it to kill an enemy antiship cruise missile in flight and trace the successful operation of these systems back to the reliability inherent in their design, to the adequacy of spare parts purchased, and to the training and experience of the crew which diagnosed and repaired prior malfunctions. However all of this is too overwhelming in magnitude, detail, and interactions to be successfully modeled. Still decision makers in the Department of Defense and the Congress want to know the answer to the question: "By how much will the warfighting outcome be changed by another 50 million dollars spent for spare parts?" Actually readiness is substituted for warfighting and "relating resources to readiness" is the question studied. Multiple linear regression is the technique most often employed to relate input resources to output readiness measures such as full mission capable rate or days free of C3/C4 casualty reports. Data problems abound in such analyses. See Ref(8) for example.

2. PLANNING MODELS FOR ACQUISITION LOGISTICS

Two planning models designed for use in connection with the procurement of conventional ordnance are discussed. The first is a collection of models known as NNOR, Non-Nuclear Ordnance Requirements. It is the model currently used coincident with the annual Navy budgeting process. In FY 1983 the annual rate of expenditure on non-nuclear threat-oriented ordnance alone was in excess of $3 billion.

Conventional ordnance is categorized as either 1) threat-oriented ordnance or 2) level-of-effort ordnance. One report, Ref(9), describes threat-oriented ordnance as that for which the need for weapons is determined mainly by the number of targets and level-of-effort ordnance as those weapons for which the need is determined by the number of shooters rather than targets. Air-to-air missiles, surface-to-air missiles, and torpedoes are examples of threat ordnance. Mk 82 bombs and sonobuoys are examples of level-of-effort ordnance, though it is not clear to the author that these definitions are formal, unambiguous, or uniformly interpreted.

NNOR encompasses both types of ordnance. For threat ordnance the process begins by partitioning the types and numbers of enemy units into ordnance types; i.e., the number of enemy bombers to be attrited by Phoenix air-to-air missiles, etc. Having then determined the number of targets for each weapon type the NNOR model calculates a set of ordnance requirements - the number of each weapon required to make its apportioned kills with a high degree of statistical confidence. This ends the NNOR methodology but a further step is required; Navy budget programmers must decide how much of each ordnance requirement to buy in the constrained budget. NNOR produces required ordnance stocks and present stocks are normally below the 'requirements' levels. The dollars needed to buy the deltas between present stocks and NNOR requirements are enormous. Figure 1, as given in Ref(9), is applicable. Thus each year Navy budget programmers are provided with updated requirements and, using the requirements as a guide, decide how much ordnance procurement by ordnance type to procure within the constrained budget. In this last step they are provided little if any analytical support.

Note that the NNOR methodology for ordnance requirements is analogous in structure, but not in detail, to the Allowance List methodology discussed previously in Section 4.A.3. There is no cost constraint and no optimization of any sort. In particular the methodology does not produce the most cost-effective 'basket' of ordnance types to procure with a given budget.

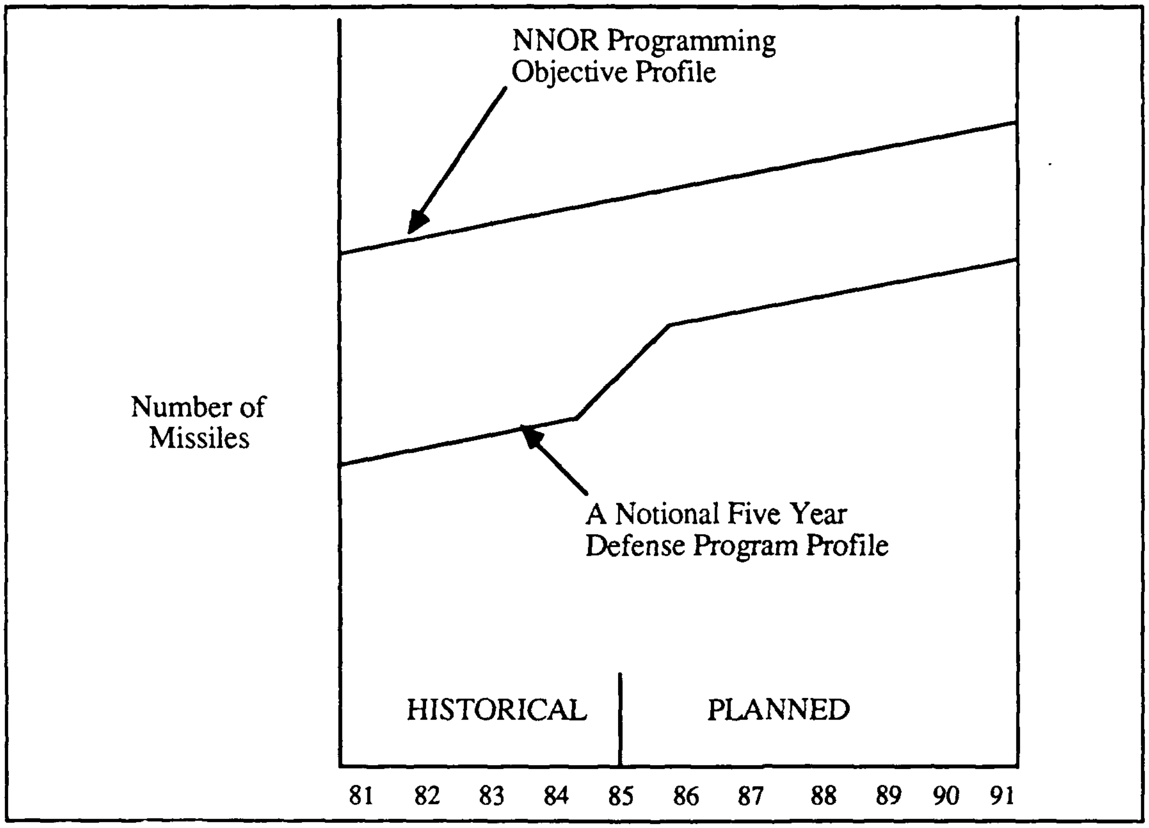

Figure 1

The cost of any basket of ordnance procurements is easily computed. The effectiveness of such procurements requires explicitly relating stocks of ordnance types to the outcomes of naval warfare. This is left as an exercise for the Navy budget programmers. Finally, getting back to the theme of this report, the measure of effectiveness in the NNOR model is statistical confidence that the stock of a given type of ordnance is sufficient to kill a specified number of enemy targets. Intuitively this is related to warfighting outcomes, but many questions remain. Passing over the questions of whether threat partitioning is appropriate and whether the requirements computations are valid, in a constrained budget environment should the Navy buy X% of all the requirements minus inventory deltas straight across the board or favor some ordnance types over others? The NNOR methodology implicitly treats all ordnance types as being of equal importance or effectiveness.

The Navy appreciated these concerns and others and, in 1981, asked the Center for Naval Analyses to look into the matter. The Ordnance Programming Model (OPM), Ref(10), was the result and dealt only with threat ordnance types. Quoting from Ref(10):

> For years the Navy has lacked a satisfactory methodology for programming threat ordnance in the yearly budget review. Ordnance 'requirements' have been calculated without serious attention to how the weapons are employed in combat, and there has been no framework to compare various programs on the basis of their cost and effectiveness.

The OPM was meant to deal with cost and effectiveness, measuring effectiveness by the contribution of ordnance stock levels to wartime naval missions. It was intended that OPM would be used as follows. An analyst or budget programmer would specify a worldwide scenario including the disposition of U.S. and enemy forces, missions, engagements, weapon lethalities, etc., etc. The analyst would then select a basket of desired ordnance stocks. How to do this is unclear but presumably no ordnance stock level would be less than the amount currently on hand and under contract. With this basket of ordnance stocks, OPM would then evaluate the outcomes of the 'war' using a deterministic, expected value computation scheme. Outcomes are expressed as the numbers of U.S. and enemy losses of ships, submarines, and aircraft as a function of time.

Performing this exercise with the present stocks of threat ordnance and again with unlimited amounts of threat ordnance would give lower and upper bounds on effectiveness. Other baskets of ordnance stocks could then be postulated, costed and evaluated as to their effectiveness. How to uniquely determine the effectiveness of a given basket of ordnance stocks when there are multiple output measures was not specified. OPM was essentially a deterministic simulation which, by itself, optimized nothing. Still one is sympathetic with the developers who recognized the necessity of trying to relate logistics expenditures (on threat ordnance in this case) to warfare outcomes.

NNOR has been around for a very long time and is still 'the' model which provides the Navy's baseline ordnance requirements. As far as is known OPM is dead. Still NNOR is not without its critics and among them was the former Secretary of the Navy, John Lehman, who wrote in the Armed Forces Journal (1983),

> It took us the first full year of the Administration to turn around the totally unrealistic peacetime planning models that the analytical community had foisted on the operators. You could only buy two torpedoes for every target in the Soviet fleet that was worth a torpedo, because you had, say, a 55% or 65% kill probability, and so two gave you over 100% and, therefore, you could not buy any more. That's the situation we were in; it was totally unrealistic.

E. BATTLE GROUP LOGISTICS

1. BACKGROUND

The following brief historical summary borrows heavily from a splendid paper by Miller, et al, Ref (11). Replenishment at sea came into being when coaling at sea became a priority matter in 1898 in connection with the blockade of the Spanish fleet at Santiago. Nineteen years later LT Chester Nimitz was project officer, engineering officer, and executive officer of the Navy's second fleet oiler and worked out a jury rig for the underway fueling of destroyers transiting the North Atlantic in World War I. Twenty-one years after this, RADM Nimitz was developing a method for refueling aircraft carriers at sea and wanted to determine the maximum speed at which underway station keeping could be established and maintained. A heavy cruiser was used to simulate a high-speed replenishment ship and the receiving ship was a destroyer commanded by LCDR Arleigh Burke. Numerous trials conducted at ever increasing speeds resulted in successful approach and station keeping for underway replenishment (unrep) at up to 28 knots.

Until the last six months of World War II replenishment in the Pacific was largely conducted in port at an advanced base to which merchant ships brought fuel, ordnance and stores from CONUS. In planning the Iwo Jima and Okinawa campaigns, Admiral Raymond Spruance was directed to conduct intensive air strikes against the Japanese home islands. Aircraft could expend their aircraft carrier's ordnance magazines in 2-4 days and the nearest advanced base at that time was 2000 miles away. Returning to base, rearming, and steaming back to station off Japan would take 10-12 days, yielding an on-station/off-station ratio of about 30%. Consequently Spruance directed his staff to develop a method to rearm at sea. The first ordnance replenishment at sea occurred in February, 1945. The ability to replenish fuel and ordnance at sea meant that two days of air strikes required only two nights and a day out of combat to replenish; replenishment occurred after withdrawal to just outside Japanese aircraft range. Fleet Admiral Nimitz declared underway replenishment to be the Navy's secret weapon of World War II.

All World War II replenishment ships were single product ships and thus a combatant was required to unrep separately with an oiler, ammo ship, and stores ship. In 1952 a German oiler which had become a war prize was commissioned and used to evaluate the utility of a multi-product replenishment ship. The German ship, though an oiler, also had cargo holds for ordnance and stores. This ship's performance with the Sixth Fleet in 1954 made a convincing case for a replenishment ship that could simultaneously transfer fuel, ordnance and stores. The last step in this brief history of underway replenishment as we know it today occurred in a 1957 conference called by the then-CNO, Admiral Arleigh Burke. It was from this conference that the modern AOE class multi-product unrep ship was conceived as bigger, faster, more capable, and cheaper to build and operate than the oiler+ammunition+stores combination of ships it would replace. The extent to which top Navy leadership played key operational and decision-making roles, in wartime and in peacetime, in the development of the Navy's formidable unrep capability is remarkable.

Today combat logistics force (CLF) ships bring fuel, ordnance, spare parts, and subsistence commodities to deployed battle groups allowing them to stay on station and to conduct continuous operations there. There are presently 57 CLF ships in the Navy representing two classes of multi-product ships and single product oilers (AO), ammunition ships (AE), and stores ships (AFS). See Table 1. The concept of operations includes a "station ship" or ships which remain with the battle group, and "shuttle ships" that transit from an advanced base to the battle group to replenish the station ship. The AOE and AOR class multi-product ships serve as station ships and the AO, T-AO, AE, AFS, and T-AFS classes of ships serve as shuttle ships, though the single-product ships can and are used as station ships at times.

TABLE 1
COMBAT LOGISTICS FORCE CHARACTERISTICS

Ship Type	Full Disp	Speed Kts.	Fuel BBl.	Ordn Tons	Stores Tons	No. Ships	Avg Age	
AOE 1	53,000	26	177K	2150	750	4	21	(1)
AOR 1	37,000	20	175K	600	575	7	18	
AO 177	26,000	20	120K			5	7	
AO 51	34,000	18	185K			3	45	
T-AO 187	40,000	20	180K			4	2	(2)
T-AO 143	27,000	20	180K			6	34	
T-AO 105	35,000	16	150K			5	43	
AE 26	18,000	20		1700		8	19	(3)
AE 21	16,000	18		1500		5	31	
AFS 1	18,000	20			3925	7	22	
T-AF 8	16,000	16			1413	1	34	
T-AFS 8	16,000	18			2893	3	22	

Notes:
(1) Four new ships, the AOE 6 class, are planned and the first is under construction.
(2) A total of 18 ships of this class are planned.
(3) The AE 36 class is planned but, through FY1991, is as yet unbudgeted. Note that the average age of the ships in the Combat Logistics Force is 24 years.

2. REPLENISHMENT TIME AND TIME OFF STATION

Since the CLF is in being, no one compares having it with not having it and having to steam back to a base to replenish. There are questions about whether the CLF numbers and characteristics are adequate, but these are not considered here. Within the battle group, measures of effectiveness for underway replenishment relate in part to Admiral Burke's observation that time spend in replenishment is time lost to the mission of the battle group. Two common measures are time spent in unrep and time off station. The time spent in unrep depends on what is needed by the combatant and the number of unrep stations on the combatant. Fuel transfer rates between all CLF ships and all combatants are standardized at 3000 gallons per minute. The actual rate of fuel transfer depends on the number of fueling stations on the unrep ship and the receiving ship. Ordnance and stores transfer rates depend upon the number of unrep stations on the unrep ship and the receiving ship and whether the receiving combatant ship has limited receiving areas and/or limiting strikedown rates. The transfer rate of missiles to combatants is one instance where the combatant's receiving/holding area and strikedown rate may drive the unrep time.

Thus the main determinants of unrep time are optempo and combatant ship characteristics. CLF characteristics seem less important with two important qualifications. The AOE is the most capable ship in the CLF with more cargo transfer stations than any other unrep ship. The AOR has limited ordnance capacity but this can be ameliorated by using an AOR and an AE in combination as station ships. The other qualification is that when the station ship is not a multi-product ship the combatant may have to unrep from more than one CLF ship depending on its needs. This, of course, will increase total unrep time. Thus it is being argued that, except for the two qualifications, total unrep time is not a great measure of effectiveness for battle group replenishment because it depends only weakly on unrep ship characteristics or operations. However if there was a proposal to reengineer the whole fleet, CLF and combatants alike, to increase fuel transfer rates or cargo transfer weights, the above conclusion would be invalid.

Total time off station is more interesting. Each combatant in the battle group is given a station in the formation based upon its warfare capability(s); i.e. AAW or ASW. At the opposite ends of the spectrum of methods of replenishing combatants steaming in a formation are the "delivery boy" scheme in which the station ship travels to the combatant and the "gas station" scheme in which the combatants come to the station ship. Because each combatant at its assigned station contributes something to the overall defensive screen of the battle group, *a combatant off station for unrep degrades the screen.* Hence the desire to minimize time off station. It follows that the delivery boy scheme is superior to the gas station scheme in minimizing combatant time off station. However the combatant will likely have some time off station even with delivery boy because the limited speed during unrep may be less than the battle group speed of advance (SOA). Further battle group formations which are greatly dispersed can, at some point, make delivery boy infeasible. An AOE station ship is considerably faster than an AOR station ship and this can become important in highly dispersed formations with a relatively high SOA. At an SOA greater than 20 knots the AOR is not a viable station ship because it can not keep up with the formation let alone act as a delivery boy. However an SOA of greater than 20 knots is likely to be incompatible with air operations and thus infeasible anyhow.

The use of time off station as a measure of effectiveness for battle group replenishment is motivated by the desire to maintain the defensive integrity of the formation. The other side of this coin is the vulnerability of the station ship which must itself be considered a high value asset. A battle group which loses its station ship has very little sustainability until it can be reached by new CLF ships or returns to port. Clearly the combat power of a battle group can be crippled by the loss of the CLF station ship. For this reason combatant time off station must be offset by a characterization of the vulnerability of the station ship and used in combination to be a satisfactory measure of unrep effectiveness.

It is proposed that deployed battle groups may be thought of as being in one of three states: in transit, in MODLOC, or in combat. Transit and MODLOC are characterized as low or medium threat environments. Combat is in a high threat environment; e.g., wartime operations inside the Soviet sea-denial zone. Transit is characterized by SOAs of 15-20 knots. In peacetime delivery boy unrep in transit is feasible with an AOE station ship. Wartime transit probably precludes delivery boy unrep due to SOA and vulnerability of the station ship. MODLOC operations are characterized by very modest unit speeds in a relatively low threat area. Delivery boy unrep works here. In combat, wartime by definition, one would hope to avoid the need to unrep at all and to have planned the tactics and battle group logistics in such a way that the battle group is self sufficient until it can withdraw from the high threat area. The station ship would accompany the battle group into combat for the flexibility and sustainability it represents to the battle group. Unrep of fuel may be avoidable with good planning but ordnance may be required between enemy raids. If so gas station offers the capability of rearming two combatants at once, each both by connected underway replenishment and by vertical replenishment, maximizing the amount of rearming possible in the (unknown) time until the next raid arrives. Gas station also provides the best protection for the station ship while operating in a high threat area.

3. MINIMUM LEVELS

A third battle group measure of effectiveness has to do with the minimum levels of combat logistics commodities experienced by units in the battle group. If a ship has a propulsion fuel (F-76) capacity of F mgals (thousands of gallons) and command has set a reserve level of, say, 60%, it is intended that the F-76 quantity should never fall below .6F. The time between unreps of F-76 will depend on F and the rate of consumption. The number of days from top-off until the fuel on board reaches .6F is $T = .4F/24f$, where f is the consumption rate in mgals per hour. Typical values for T are 3-7 days or longer depending on the ship type and its speed in knots.

Whether the combat logistics commodity is propulsion fuel, aviation fuel, specific ordnance types, or something else, the minimum levels will be the reserve levels or higher so long as underway replenishment can be conducted as required. Unrep can be conducted as required so long as it is not precluded by enemy or own operations, so long as there is a station ship, and so long as there are sufficient quantities in the station ship. An AOE can refuel (from 60% back to 100%) a conventional carrier battle group about 2.3 times. At this point the station ship needs to "consol," to consolidate its remaining fuel load with what it can take from a shuttle ship. The AO 177 class oiler, potentially either a shuttle ship or a station ship, is described as having been sized to provide two refuelings for a conventional carrier battle group. Though propulsion fuel has been discussed, the same situation holds for any combat logistics commodity. Thus the minimum levels will be the reserve levels or greater provided there is a station ship, provided there are sufficient timely visits by shuttle ships, and provided there is enough of the various commodities to refill the shuttle ships as required. Loss of the station ship, shuttle ships, or stocks at an advanced base due to enemy action would necessitate the withdrawal of the battle group from combat until the losses can be made up. Minimum levels as a measure of effectiveness is useful in looking at the adequacy of a logistics support plan which specifies the numbers of each type of shuttle ship that will be available.

There are three recent, computer-based models that seek to analyze battle force logistics in terms of some or all of the following measures: the amount of material expended and replenished during an operation, the number and mix of CLF ships needed to support an operation, and the delivery methods used by CLF station ships. The models are the Replenishment-At-Sea Model (RASM), Ref(12), the Battle Force Operations Requirement Model (BFORM), Ref(13), and the Resupply Sealift Requirements Generator/Ship On-Line Scheduler (RSRG/SOS), Refs(14) and (15).

The BFORM model provides data on minimum levels experienced during a battle force operation. BFORM and RASM provide combatant time off-station statistics. RSRG/SOS does not provide output related to individual ships, but will examine the adequacy of a logistics support plan quite readily. Other battle force measures of effectiveness can be computed if one is willing to trace through lengthy event lists output by the models.

4. SUSTAINABILITY

The sustainability of a battle group is conceptually attractive as the ultimate measure of logistics effectiveness because it depends on all three parts of the Navy logistics system: acquisition, in-service support, and operational logistics. In terms of combat logistics commodities the following definitions of sustainability are offered. Ship propulsion fuel, F-76, is most usefully characterized in days of steaming. If at a given time the quantity of F-76 in a combatant is 84% of capacity, the sustainability it represents is (.84-.60)F/24f days, where f is the burn rate in mgals per hour for that ship at a given speed in knots. For example let's say a Leahy class cruiser has an F-76 capacity of 450,000 gallons and will burn 1092 gallons per hour at 15 knots. If the current F-76 level is 84% of capacity and if the reserve level is 60%, then the ship has a current F-76 sustainability of 4.12 days at 15 knots.

Aviation fuel, JP-5, is used in fixed wing and rotary wing aircraft and can be used for ship propulsion fuel if necessary. How should sustainability be measured for JP-5? In the absence of a specific threat or a specific offensive action by the battle group, there is a normal amount of flying done to maintain a defensive posture (CAP, early warning, ASW) and training and maintenance flying on a daily basis. This flying can be characterized in terms of the numbers of specific aircraft types and their number of sorties per day. Using the number of gallons of JP-5 required per sortie it is easy to compute the total amount of JP-5 that will be consumed per day for normal flight operations. It would then be prudent to reserve a quantity of JP-5 for some number of days of normal flying, say, 3 days (adequate to withdraw from a high threat area if necessary).

On top of normal flying requirements are requirements for specific offensive or defensive events; i.e., strikes or defense against enemy raids. Again characterize the strike or raid events in terms of the types and numbers of aircraft, including tankers if appropriate, and determine the total number of gallons of JP-5 used by a strike or raid. In the models used by the author these totals are roughly equal. Thus one might characterize the JP-5 sustainability of the aircraft carrier at a given time by first reserving X days worth of JP-5 for normal flight operations and describing the balance in terms of the number of strikes or raids that quantity represents. For example let's say a carrier has a JP-5 capacity of 1500 mgals. If 3 days of normal flying in a high threat area requires 600 mgals, if the current JP-5 fuel state is 1100 mgals, and if a raid or strike requires 100 mgals, then the JP-5 sustainability at that time is 5 raids or strikes. JP-5 unrep to the carrier could be triggered by a percent reserve criterion or by sustainability measured in raids or strikes criterion. No mention has been made of the JP-5 requirements of surface combatants for ASW helo operations. In total the surface combatants hold only 6% of the battle group's JP-5 total capacity and each combatant has enough JP-5 for a relatively large number of helicopter sorties. Thus surface combatant JP-5 requirements are not likely to drive battle group logistics requirements.

The situation with ordnance sustainability is somewhat analogous to JP-5. Threat-oriented ordnance usage is probably related to specific events such as raids, strikes or ASW prosecutions. For some ordnance types, sonobuoys for example, usage can probably be reckoned in terms of days (of operations at sea). For surface combatants which are AAW missile shooters, standard missile sustainability should be characterized in terms of the number of raids which could be engaged; i.e., 0,1,2,... depending on the magazine quantity on hand and the expected raid size. Similarly anti-ship cruise missile sustainability would be characterized as representing 0,1,2,... strikes depending on the weapon load remaining and target type. One difference between ordnance and fuel is that where unrep of fuels is routine, some ordnance types are difficult to unrep at sea (very slow rates) and some threat ordnance types are not planned for unrep at sea; i.e., long range antiship missiles. In the case of the latter, sustainability can not be restored except by returning to port.

It is suggested that the use of "number of raids" or "number of strikes" is more meaningful than days of supply. The notion of days of supply is acceptable for food, propulsion fuel, and some ordnance, but is not the most appropriate for commodities whose usage is dictated by events rather than just the passage of time. The temptation to convert from raids or strikes to kill of enemy ships, aircraft, or facilities is resisted because the conversion would necessarily involve additional models and assumptions. In characterizing standard missile stocks in terms of the number of raids, the outcome of the enemy raid is not predicted. Rather the sustainability measure is just the number of raids for which there are sufficient missiles on hand to legitimately engage the enemy.

Obviously battle group sustainability in combat logistics commodities depends in the first instance on the station ship and its survival. Next in the support chain are the shuttle ships, the adequacy of their numbers for the forces to be supported and the transit distances involved, and their survival and that of their cargos. Just behind the shuttle ships are the advanced bases they will operate from. Continental US ports are the fallback if advanced bases are not available or denied to us, but shuttle ship transits would be longer effectively increasing the number of shuttle ships and escorts required.

a. Fleet Logistics Sustainability Assessment

A major fleet logistics sustainability assessment was undertaken within the last year. In a marvelously complete and thorough analysis the situation with regard to various items representing logistics resources was assessed and characterized. Generally the baseline requirements were derived from the logistics resources necessary to successfully execute a given operations plan (OPLAN). The measure of effectiveness was usually the percent of the requirement that was available at the time of the assessment. Depending upon the percentage of the requirement available a rating of S1, S2, S3, or S4 was assigned with S1 interpreted as good and S4 as bad. The analysis considered over 100 separate categories of logistics resources from fuels and ordnance types to facilities, transportation assets and personnel.

The assessment was undertaken to characterize logistical readiness to execute a given OPLAN and to support budget formulation. The cost of correcting deficiencies could easily be computed. Various levels of funding could be considered such as the cost of bringing all categories of logistics resources up to 100% of the requirement, to 90% of the requirement, etc. The approach used in the fleet logistics sustainability assessment presumes that there is a rigorous, accurate methodology for determining requirements. If we take this as a given, there is still the problem of assessing the risk or criticality of being at only a reduced percent of requirement in each of the logistics resource categories.

In other words while the cost of correcting the perceived deficiencies is easily determined, the benefit from spending this money or the risk associated with not spending the money are not addressed and are unclear. The percent of requirement met by available assets is essentially a "logistics measure;" dollars input to buy logistics resources are related to the logistics output measure which is "percent of requirement met."

The problem is that the Navy, Defense planner, or member of Congress is not provided with a feeling for the most critical problems to fix with a limited budget. Critical here refers to the ability of the fleet to execute the OPLAN. Just as all items are not equally expensive, so also all items are unlikely to be equally important to the successful execution of the OPLAN. The fleet logistics sustainability assessment however implicitly treats all requirement shortfalls as equally important. The decision maker really needs to know the contribution of each type of logistics resource.

One approach to determining the criticality or relative importance of individual types of logistics resources to OPLAN execution is to quantify the judgements of knowledgeable persons who are asked to compare the items. This approach was taken in a recent Naval Postgraduate School thesis, Ref(16), which sought to prioritize advanced base functional components (ABFCs). A reasonably large number of knowledgeable officers were asked to make categorical judgements and pairwise comparisons on a reduced set of the most important ABFCs. There are over 200 ABFCs and annually the Fleet Commanders-in-Chief (FLTCINC) are asked to list the 30 ABFCs most critical to their theater and OPLANS. In Ref(16) the eleven ABFCs most frequently mentioned in the June 1987 FLTCINC reports were used in the study. Two survey instruments designed to elicit categorical judgements and pairwise comparisons were sent to 24 knowledgeable officers. They were asked in each case to make judgements as to the importance of each ABFC to the successful execution of a general OPLAN, a "base case." Categorical data was obtained by asking the subject experts to place each of the ABFCs into one of four categories ranging from "no effect" on OPLAN execution to "war stopping." These categorical judgements were then used to establish an interval scale, Ref(17). Figure 2 shows the interval scale of the relative importance of each of the eleven ABFCs.

In the second survey instrument the experts were asked to make pairwise comparisons of all pairs of ABFCs and give for each an "intensity value" ranging from "equal importance" to "absolute importance" of one ABFC over the other. These comparisons were then analyzed using both the Constant Sum Method, Ref(18), and Saaty's Analytical Hierarchy Process, Ref(19). Though the numerical scale values are different, the rankings produced by these two methods are identical. Figure 3 shows the ranking and scale produced by the Constant Sum Method. Finally, the agreement between the categorical and pairwise responses is quite good as comparing Figures 2 and 3 indicates. The respondents found the categorical response survey easier than the pairwise comparison survey and of course the number of items that can be considered in asking for pairwise comparisons is limited since the number of comparisons is $n(n-1)/2$, where n is the number of items being considered.

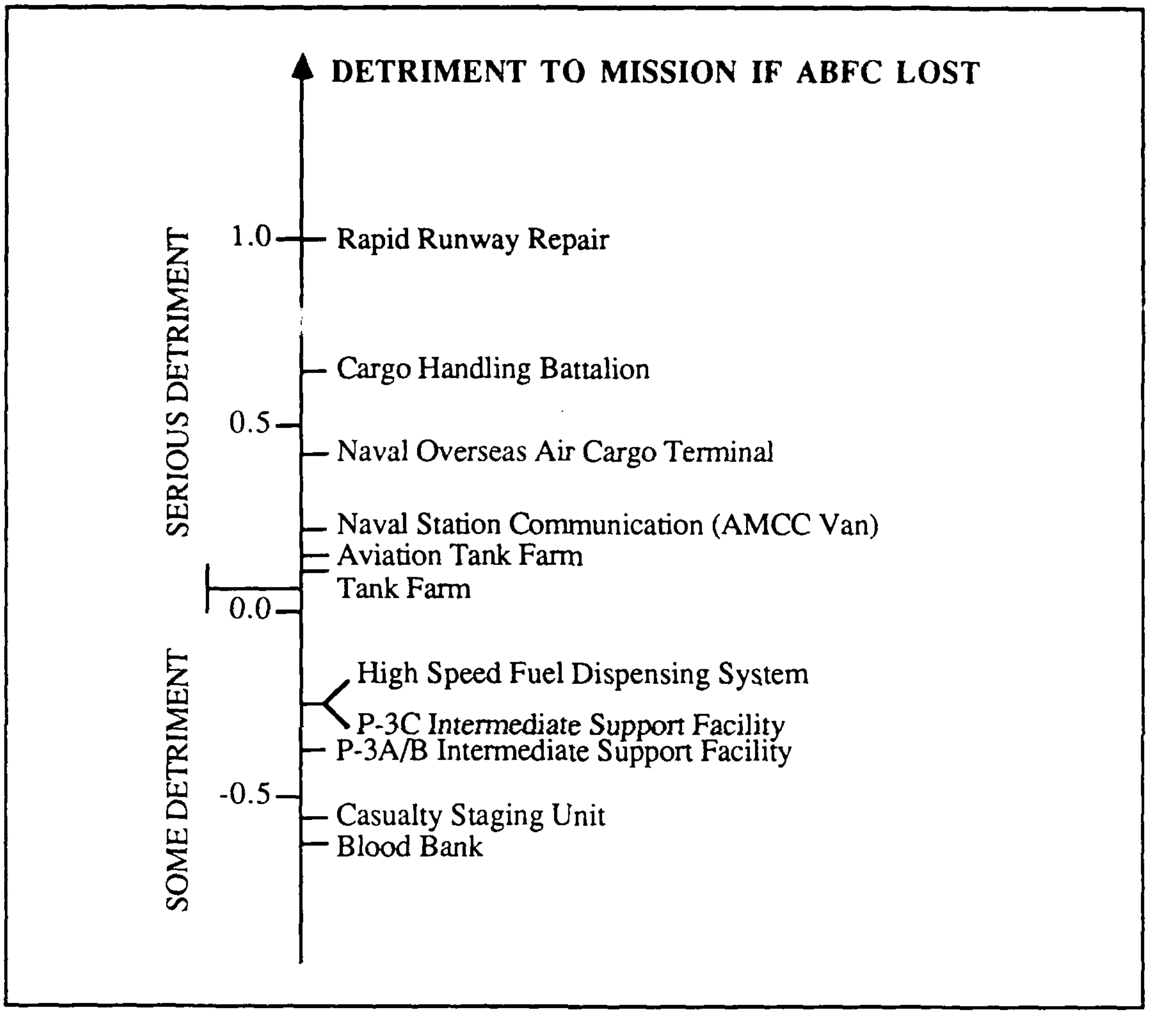

Figure 2. Scale Obtained using Categorical Judgments

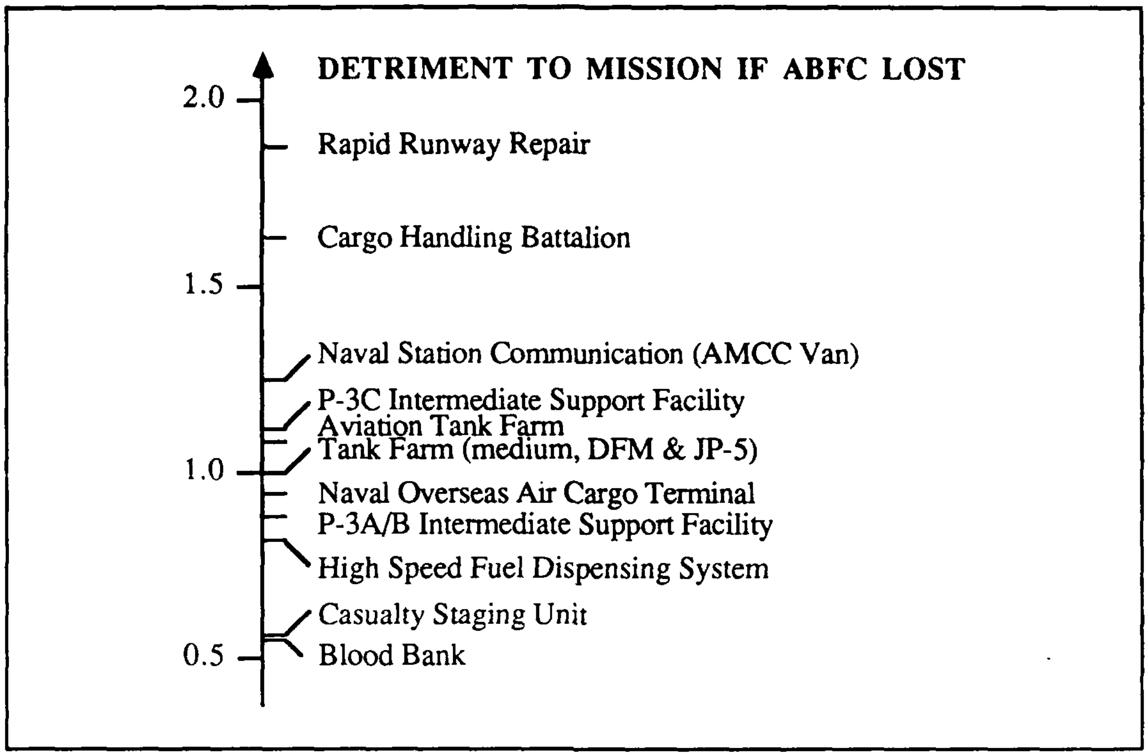

Figure 3. Scale Obtained using Constant Sum Method

F. CONCLUSION

In the section on Sustainability the author introduced the idea of characterizing the state of combat logistics commodities in a battle group in terms of days of endurance or the number of events (strikes or raid defense) the battle group could legitimately undertake. These measures are not measures of effectiveness so much as they are a taxonomy for battle group logistics decision aids. Still they relate logistics resources to warfighting and thus seem to be a step in the right direction.

The other idea presented in that section was that of using expert judgements to obtain utility scales representing the relative worth of one subcategory of logistics resource compared to the others in that category. To be responsive to the needs of defense planners this process would have to be expanded to where it considered the various categories of logistics resources (ABFCs vs. ordnance stocks vs. CLF ships, etc.), and logistics resources against other forms of defense expenditure (personnel, training, ships, aircraft, steaming days, weapon systems, R&D, etc.). This seems to be an unrealistically large undertaking however, even if one has no reservations about using expert judgements for decision making.

Thus this report has focused on measures of effectiveness in logistics and the central theme has been that, at best, dollars spent on logistics resources can today only be related to logistics output measures. One would like to be able to characterize logistics dollars spent in terms of their contribution to warfighting outcomes. Without this ability, logistics will be relatively low priority and the logistics system will be funded at levels which are adequate in the main to meeting only peacetime requirements.

In the event of conflict, all uncertainties with regard to how logistics relate to warfighting outcomes will resolve themselves fairly rapidly. The only problem is that the pace of the conflict may not allow sufficient time for the acquisition of the logistics resources required. The Falkland Islands conflict lasted only 73 days yet the British expended ordnance against real and false targets at such rates that shortages of some types of ordnance were experienced. These shortages could of course not be made up during the conflict and the British were forced to use ordnance stocks earmarked for NATO contingencies, Ref(20).

The issues in developing meaningful logistics measures of effectiveness are clear. How to proceed is unfortunately unclear. In the absence of operational measures of effectiveness for logistics, Navy budget planners and decision makers in DOD and the Congress are left with difficult tasks. They must decide "how much logistics in enough" without much help from analysis.

REFERENCES

1. The Management of Business Logistics , by J.J. Coyle and E.J. Bardi, West Publishing Co., 1984.

2. "Logistics Systems Concepts," report of a two-day conference, 16-17 August 1988, David Taylor Research Center.

3. "Navy Logistics System," OPNAVINST 4000.85, 18 September 1986.

4. "Wholesale Provisioning Models: Model Development," by Alan McMasters and F.R. Richards, Naval Postgraduate School, NPS 55-83-026, September 1983.

5. "Wholesale Provisioning Models: Model Evaluation," by Alan McMasters, Naval Postgraduate School, NPS 55-86-011, May 1986.

6. "Wholesale Provisioning Model Functional Description," Fleet Material Support Office memorandum, 30 September 1986.

7. "Determination of Initial Requirements for Secondary Item Spares and Repair Parts," DODINST 4140.42, 7 August 1974.

8. "Modelling DD-963 Class Material Readiness," by LCDR Jonathan E. Will, USN, masters thesis, Naval Postgraduate School, September 1988.

9. "Notes from the Stockpile Seminar," by D.C. Boger and A.W. Washburn, Naval Postgraduate School, NPS 55-85-014, August 1985.

10. "Documentation of the Ordnance Programming Model," by D.B. Levine, et al, Center for Naval Analyses, 83-0718.08, June 1983.

11. "The Development of the U.S. Navy Underway Replenishment Fleet," by Marvin O. Miller, J.W. Hammett and T.P. Murphy, paper presented at the annual meeting of the Society of Naval Architects and Marine Engineers, New York, November 1987.

12. "Mathematical Description of the Replenishment-At-Sea Model (RASM)," by D.L. Branting, Center for Naval Analyses, December 1986.

13. "Battle Force Operations Requirement Model - BFORM Functional Description and User's Manual," by L. Hereford and R. Spiegel, Applied Physics Laboratory, Johns Hopkins University, March 1988.

14. "Resupply Sealift Requirements Generator User's Manual," by C. Vondersmith and E. Miller, David Taylor Research Center, June 1988.

15. "Ship On-Line Scheduler, Version II (SOS2) User's Manual," by R. Melton, David Taylor Research Center, June 1988.

16. "Prioritization of Advanced Base Functional Components," by LCDR Linda A. Guadalupe, USN, masters thesis, Naval Postgraduate School, September 1988.

17. "On Constructing Interval Scales from Categorical Judgements," by Glenn F. Lindsay, unpublished paper, Naval Postgraduate School, September 1981.

18. "Scaling with the Constant Sum Method," by Glenn F. Lindsay, unpublished paper, Naval Postgraduate School, February 1980.

19. The Analytical Hierarchy Process: Planning, Priority Setting, Resource Allocation, by Thomas L. Saaty, McGraw-Hill Book Co., 1980.

20. "Lessons of the Falklands," summary report, Office of Program Appraisal, Department of the Navy, February 1983.

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